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NEW RIVER GORGE NATIONAL RIVER
  WEST VIRGINIA

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SUMMARY

On November 1, 1991, the National Institute for Occupational Safety an
Health (NIOSH) received a request for a health hazard evaluation (HHE)
the U.S. Department of Interior, National Park Service (NPS). The pur
the HHE was to characterize fire fighters' exposures to chemical conta
during fire suppression operations. Industrial hygiene data was colle
November 3 and 4, 1991, during the Gauley Mountain Fire at the New Riv
National River in West Virginia.

During the HHE, personal breathing zone (PBZ) and area air samples wer
collected to measure airborne concentrations of carbon monoxide (CO),
dioxide (SO_2), aldehydes, volatile organic compounds (VOCs), respirabl
particulate matter (RPM), crystalline silica, benzene solubles, and
polyaromatic hydrocarbons (PAHs).

Eight-hour time-weighted average (TWA) exposures ranged up to nine par
million (ppm) for both CO and SO_2, with average exposures of four and
respectively. CO exposures were well below the NIOSH recommended expo
limit (REL) of 35 ppm. Twenty-three of the 40 PBZ measurements
SO_2 exposures were at or above the NIOSH REL of two ppm. Formaldehyde
concentrations ranged up to 0.10 ppm. NIOSH considers formaldehyde to
potential occupational carcinogen, and recommends that exposures be re
the lowest feasible level. Air concentrations of other aldehydes dete
acetaldehyde, acrolein, and furfural, were below the minimum quantifia
concentrations (MQC). VOCs were not detected. Air concentrations of
ranged up to 1.5 milligrams per cubic meter (mg/m^3). Silica was not d
Air concentrations of benzene solubles ranged up to 0.67 mg/m^3; howeve
were not detected on these samples. Air concentrations of naphthalene
measured from the tube portion of the PAH samples ranged up to 6.1 mic
per cubic meter ($\mu g/m^3$). This is well below the NIOSH REL of 50 mg/m^3.
Concentrations of other PAHs were below the MQC.

Results indicate that fire fighters were overexposed to SO_2 during
wildfire suppression activities. Recommendations for reducing SO_2
exposures, and for future collection of exposure data are
provided.

KEYWORDS: SIC 0851 (Forestry Services); forest fire fighting; carbon
monoxide; sulfur dioxide; aldehydes; volatile organic compounds; parti
matter; crystalline silica; benzene solubles; polyaromatic hydrocarbon

INTRODUCTION

On November 1, 1991, the National Institute for Occupational Safety an
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during fire suppression operations. Industrial hygiene data was colle
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National River in West Virginia.

NIOSH assistance in evaluating chemical exposures of wildland fire fig
was first requested in 1988. The NPS requested assistance from NIOSH
identifying and quantifying the potential exposures to chemicals in sm
in evaluating the impact of inhalation of this smoke on the health of
fighters. In 1988, data was collected during the Yellowstone National
fires which swept through nearly half of the park's 2.2 million acres
(HETA 88-320-2176).[1] In 1990, data was collected at Yosemite National
during the Arch Rock Fire (HETA 90-365); a report summarizing the find
this study is currently being prepared. In 1991, data was collected d
the Thompson Creek fire at Gallatin National Forest[2] and during the Ga
Mountain Fire at the New River Gorge National River.

BACKGROUND

There are two distinct classifications of wildland fires, prescribed a
wildfire. A prescribed fire is designated as such when it is in the
"prescription" of the burn. The prescription includes a specific geog
area and predetermined burning properties, such as flame height and fu
consumption. Conversely, a wildfire is a wildland fire that is outsid
prescription.

Wildfire suppression activities may have up to five stages for a given
dispatch, initial attack, buildup, mop-up, and demobilization. After
is spotted and the location is identified, fire fighters are dispatche
fire for initial attack. If initial attack activities do not control
fire, build-up of suppression activities to a project or campaign fire
place. Once the fire is controlled, demobilization of resources occur
this point mop-up efforts, the actual extinguishment of all fire, are
focus of suppression activities.

Although the strategies used to fight forest fires can vary dramatical
techniques used from one fire to another are basically the same. Fire
suppression relies on removing one or more of the three requirements o
fire: oxygen (O_2), fuel, and heat. For an uncontrolled fire, suppres
efforts focus on removing the vegetation which is the fuel for the fir
Procedures that remove heat and O_2 are relied on during the mop-up sta

Fire fighters use hand tools to remove vegetation down to the mineral
thus forming containment lines around the fire. The containment lines
referred to as fireline. When firelines are constructed adjacent to t

it is referred to as direct attack line construction. When they are
constructed at a distance from the fire, it is referred to as indirect
Direct attack generally requires less time to control the fire, and re
less acreage burned. However, direct attack usually requires building
fireline, with personnel working nearer to the heat and smoke. Direct
therefore, is generally considered to result in greater exposures of f
fighters to smoke than is indirect attack. Air attacks, i.e., the dro
water or fire retardant from various types of aircraft, is used to slo
progress of the fire and to extinguish spot fires that may develop dow
the main fire. To remove fuels from areas ahead of the advancing fire
affect the direction or spread of the wildfire, unburned areas of land
ignited intentionally within prescription. During this operation, ref
as burning out or backfiring, fire fighters are required to "hold the
to insure that the fire does not escape its prescription.

Forest fire fighters typically work 12 hours per day, six to seven day
week. They are allowed to work up to 13 days straight, at which time
must take one day off (after 21 days, they are required to take two da
The crew is usually transported by ground or air to and from staging a
The duration of time that a fire fighter spends in travel during one s
range from minutes to hours. This depends on the distance between the
area and base camp, and the number of staging areas that the fire figh
travels to during that shift. After arriving at the staging area, cre
spend up to several hours hiking before initiating line construction.

During suppression activities, fire fighters typically wear Nomex™ pan
shirt, Vibram™-soled boots, hard hats, goggles and leather gloves. No
a chemically treated material which is flame resistant. It will burn
an ignition source is present. This differs from plain cotton which w
continue to burn when the ignition source is removed.

Because fire suppression strategies can vary depending on fire behavic
smoke exposure which fire fighters experience can also vary dramatical
this reason, NIOSH investigators targeted their efforts at fires which
appeared to have the potential for prolonged direct attack activity, w
were believed to result in the greatest exposure, i.e., monitoring the
case. To collect exposure data on direct attack, it is critical that
collection occur during the early stages of fire suppression, because
fire is contained, prolonged direct attack is less likely.

On November 1, the NIOSH team was dispatched to the fire out of Region
the United States Forest Service (USFS). On November 2, the team memb
at base camp preparing to collect data the following day. (Data colle
began within 36 hours of being dispatched.)

The crew monitored, the Alpine Hot Shots, was selected through the coo
of the local Incident Commander. A "Hot Shot" crew, also called a Typ
crew, was chosen because they are more likely to perform direct attack
Type 2 crew, which generally performs indirect attack and mop-up. Tho
designated as a "Hot Shot" crew, the Alpine crew at the Gauley Mountai

consisted of Type 1 crew members from the Alpine Hot Shots, and member various Type 2 crews.

A crew typically consists of one superintendent who is in charge of up squads. Each squad is led by a squad boss who is in charge of approxi five fire fighters. Some of the fire fighters, referred to as sawyers chainsaws during line construction to remove trees and other large fue majority of the fire fighters use manual tools designed specifically f removing fuels.

On November 3, the crew backfired up a hill from a dirt road. The roa utilized as a natural fire break; therefore, firelines were not constr that day. The crew monitored the road to assure that the fire did not onto the downhill slope. Crew members described the smoke exposure du that shift as very low. On November 4, the crew constructed fireline (indirect attack), and backfired from another dirt road. Crew members described the smoke exposure as low during most of that shift and mode during one intense backfiring operation that lasted approximately 45 m Crews worked 12 hours each day including travel time. The amount of t time each day was approximately three hours; this included time spent transport and hiking.

METHODS

Data collected at the Gauley Mountain Fire consisted of personal breat zone samples (PBZ) full-shift air measurements for the following analy carbon monoxide (CO), sulfur dioxide (SO_2), respirable particulate matter (RPM), crystalline silica, aldehydes, benzene solubles, and polyaromatic hydrocarbons (PAHs). These compounds were chosen based o previously collected by NIOSH and other investigators that suggests th compounds may be present during wildfires or prescribed burns.[1-4] A to 20 fire fighters were monitored for two days (November 3 & 4). One an measurement for each of the above analytes was made at the Canyon Rim Visitor's Center on November 4. These measurements were made using th methods as for PBZ samples.

<u>CO and SO_2</u>

Thirty-nine PBZ measurements for CO and 40 PBZ measurements for SO_2 we using Dräger long-term diffusion tubes. The average duration of these was 8.2 hours. The Dräger tubes are colorimetric indicators which pro length of stain proportional to the time-weighted average (TWA) concen The range of measurement for an eight hour sample is 6 to 75 parts per million (ppm) for CO and 0.7 to 19 for SO_2.[5] The relative standard dev of the method is reported to be 25% for CO at an air concentration of and 20% for SO_2 at an air concentration of 2 ppm.

Aldehydes

Ten PBZ measurements were made for aldehydes using NIOSH Method 2539.[6] air was drawn through an SKC sorbent tube (catalog number 226-30-15-2) flowrate of 0.05 liters per minute (lpm) using a portable battery-powe sampling pump. The average sample volume was 28 liters. The samples analyzed by gas chromatography for the following aldehydes: acetaldeh formaldehyde, acrolein and furfural.

Volatile Organic Compounds (VOCs)

Ten PBZ measurements for VOCs were made using NIOSH Methods 1003, 1500 1503. Sample air was drawn through a standard charcoal tube using a p battery-powered sampling pump at a flow rate of 0.05 lpm. The average volume was 29 liters. After sampling, the charcoal was desorbed with carbon disulfide and the samples were qualitatively screened by gas chromatography (GC) and mass spectroscopy. Based on these results, st were prepared and the samples were quantitated for benzene, toluene, x and trimethylbenzene by GC.

RPM and Silica

Nine PBZ measurements of RPM were made using NIOSH Method 0600.[6] Samp was drawn through a Dorr-Oliver cyclone and then through a tared polyv chloride filter (37 millimeter diameter, 5 micron pore size) at a flow 1.7 lpm using a portable, battery-powered sampling pump. The average volume was 890 liters. The cyclone removes the non-respirable particu from the airstream, that which has an aerodynamic diameter of greater 10 micrometers (μm). A determination of the weight of the RPM deposit each sample was made by weighing the filters on an electrobalance afte collection and subtracting the previously determined tare weights. Th samples were then analyzed for respirable crystalline silica content b diffraction (NIOSH Method 7500).[6]

Benzene Solubles and PAHs

Nine measurements of benzene solubles, and both particulate and gaseou of PAHs, were made using NIOSH Methods 5023 & 5515. Air was drawn thr polytetrafluoroethylene filter and sorbent tube (washed XAD-2 resin ir sorbent tube, manufactured by Supelco Inc.) in series, at a flow rate 1.0 lpm using a portable, battery-powered sampling pump. The average volume was 530 liters. The filter collects the PAH-containing particu matter, whereas the sorbent tube collects the gaseous PAHs. The filte sorbent tube samples were extracted with benzene. Aliquots of the ext from the filters were evaporated to determine the benzene-soluble frac the extract (NIOSH Method 5023). Separate aliquots of the filter and extracts were injected into a GC-FID and analyzed for the following PA naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, ant fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoanthene

benzo(k)fluoranthene, benzo(e)pyrene, benzo(a)pyrene, indeno(1,2,3-c,d
dibenz(a,h)anthracene, and benzo(g,h,i)perylene.

EVALUATION CRITERIA

General Guidelines

As a guide to the evaluation of the hazards posed by workplace exposur
NIOSH field staff employ environmental evaluation criteria for assessm
number of chemical and physical agents. These criteria are intended t
suggest levels of exposure which most workers may be exposed up to 10
per day, 40 hours per week, for a working lifetime, without experienci
adverse health effects. It is, however, important to note that not al
workers will be protected from adverse health effects if their exposur
maintained below these levels. A small percentage may experience adve
health effects because of individual susceptibility, a pre-existing me
condition, and/or a hypersensitivity (allergy).

In addition, some hazardous substances may act in combination with oth
workplace exposures, the general environment, or with medications or p
habits of the worker to produce health effects, even if the occupation
exposures are controlled at the level set by the evaluation criterion.
combined effects are often not considered in the evaluation criteria.
some substances are absorbed by direct contact with the skin and mucou
membranes, and thus, potentially increase the overall exposure. Final
evaluation criteria may change over the years as new information on th
effects of an agent become available.

The primary sources of environmental evaluation criteria for the workp
the following: 1) NIOSH criteria documents and recommendations, inclu
recommended exposure limits (RELs), 2) the American Conference of Gove
Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs), and 3) th
U.S. Department of Labor, Occupational Safety and Health Administratio
permissible exposure limits (PELs). The OSHA standards may be require
take into account the feasibility of controlling exposures in various
industries where the agents are used; the NIOSH-recommended standards,
contrast, are based primarily on concerns relating to the prevention o
occupational disease. Industry is legally required by the Occupationa
and Health Act of 1970 to meet those levels specified by an OSHA stand
The requirements of the act were extended to federal employees in 1980
executive order 12196, Occupational Safety and Health Programs for Fed
Employees.

A full-shift TWA exposure refers to the average airborne concentration
substance during a normal 8- to 10-hour workday. Some substances have
recommended short-term exposure limits (STEL) or ceiling values which
intended to supplement the TWA, where there are recognized toxic effec
high short-term exposures.

Listed below is a brief summary of the known health effects from overe
to the chemicals which were monitored during this survey.

Carbon Monoxide

Carbon monoxide is a colorless, odorless, tasteless gas produced by in
burning of carbon-containing materials; e.g., vegetation. The initial
symptoms of CO poisoning may include headache, dizziness, drowsiness,
nausea. Advanced symptoms include vomiting, loss of consciousness, an
collapse if prolonged or high exposures are encountered. Coma or deat
occur if high exposures continue.[7-12] The NIOSH REL and OSHA PEL for a
TWA are 35 ppm. The ACGIH TLV is 25 ppm (this was reduced from 50 ppm
year).[13] The REL was developed by NIOSH using the Coburn, Foster, Kane
equation.[7] It is designed to reflect the 8-10 hour TWA exposure to CO
would result in a 5% carboxyhemoglobin (COHb) level for individuals wo
a low level of activity at an elevation close to sea level. NIOSH rec
adjusting the REL when environmental conditions or work loads differ f
those which the guideline was designed.[7] After adjusting for these fa
the NIOSH investigators calculated RELs of 17 and 21 ppm for fire figh
the Yellowstone and Thompson Creek fires respectively.[1,2] Based on the
conditions observed for fire fighters during the Gauley Mountain Fire,
adjusted REL of 30 ppm CO was calculated. The calculation of this val
the parameters used in its calculation are provided in Appendix I.

Sulfur Dioxide

SO_2 is a colorless gas that results from the combustion of sulfur-cont
materials. It is a severe irritant of the eyes, mucous membranes, ski
the upper respiratory tract. The irritation of the upper respiratory
can result in changes in pulmonary mechanics due to irritant induced
bronchoconstriction.[14-17] Individuals who suffer from asthma are partic
sensitive to SO_2 exposure, experiencing pulmonary effects at levels of
1 ppm.[18] The NIOSH REL, OSHA PEL and ACGIH TLV for an 8-hour TWA are 2

Aldehydes

Collectively, aldehydes constitute a broad class of organic compounds
are highly reactive biochemically. Acute health effects from exposure
aldehydes can include irritation to the eyes, nose, throat and mucous
membranes; chemical sensitization; and pulmonary edema at higher
concentrations.[19,20] The OSHA PEL and ACGIH TLV for acetaldehyde,
formaldehyde, acrolein, and furfural are 100 ppm, 1 ppm, 0.1 ppm, and
respectively. NIOSH considers acetaldehyde and formaldehyde to be pot
occupational carcinogens and recommends that exposures be reduced to t
lowest feasible level. The NIOSH REL for acrolein is 0.25 mg/m^3. NIO
not currently have an exposure guideline for furfural.

Respirable Particulate Matter (RPM)

RPM refers to particulate material that has a mean aeromatic diameter
10 micrometers or less. Because of their small size, these particles
capable of reaching the alveolar region of the lung; hence, they are r
to as respirable particulate. NIOSH does not have an REL for RPM. OS
established a PEL of 5 mg/m^3 for respirable particulate not otherwise
regulated (RPNOR). NIOSH investigators feel that the OSHA PEL for RPM
not an appropriate evaluation criteria for wildland fires, because pre
research has demonstrated that smoke from forest fuels can contain a v
of toxic compounds including PAHs.[21]

Crystalline Silica

Crystalline silica consists of clear crystals composed of silicone and
that can be present in soils and become airborne when soil is disturbe
Exposure to crystalline forms of silica: quartz, cristobolite, tridym
tripoli are known to cause silicosis,[22] a disabling form of pulmonary
fibrosis.[a] NIOSH considers all forms of crystalline silica to be pote
human carcinogens. The OSHA PEL and ACGIH TLV are 0.1 mg/m^3 for quart
0.05 mg/m^3 for cristobalite.

Polyaromatic Hydrocarbons (PAHs)

PAHs constitute a large class of organic compounds that consist of two
fused aromatic rings. They are often associated with the combustion c
pyrolysis of organic matter, especially coal, wood, and petroleum proc
The analytical method for PAHs measures 17 individual compounds. Eval
criteria for the majority of these compounds do not currently exist.
NIOSH REL and OSHA PEL for naphthalene is 50 mg/m^3. For Chrysene, NIO
recommends that exposures be reduced to the lowest feasible level beca
the carcinogenic potential of chrysene. The OSHA PEL for coal tar pit
volatiles pertains to emissions containing PAHs that result from the k
of wood as well as coal. This standard of 0.2 mg/m^3, is for benzene-s
from which at least one of the following PAHs has been identified:
anthracene, benzo(a)pyrene, phenanthrene, acridine, chrysene, or pyren

RESULTS AND DISCUSSION

Eight-hour TWA exposures for CO and SO_2 are presented in Table 1. Exp
ranged up to 9 ppm for both CO and SO_2. Average exposures for CO and
4 and 2 ppm, respectively. One SO_2 measurement of 9 ppm was much grea
the other 39 samples which ranged from 1 to 3 ppm. An explanation for
was not identified. Twenty-three of the 40 PBZ exposures measured for
were at or above the NIOSH REL of 2 ppm.

Reducing SO_2 exposures requires the removal of SO_2 emissions from the a
is inhaled, or a reduction in the time that fire fighters are in areas

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[a]   Pulmonary fibrosis refers to the formation of fibrous tissue
        the lung which generally impairs pulmonary function.

elevated concentrations of SO_2. The reduction of SO_2 exposures during
suppression activities through engineering controls such as local exha
ventilation is not feasible for wildland fires. Respirators approved
for controlling SO_2 exposures include chemical cartridge respirators (
and air supplied respirators (ASRs). Fire suppression agencies may ch
use CCRs; however, employee discomfort, the additional pulmonary load,
reliance on employee cooperation, are factors which must be considered
beforehand. If CCRs are used, a complete respiratory program consiste
the OSHA respiratory standard (29 CFR 1910.134)[23] should be implemented
ASR, either an airline type or self-contained breathing apparatus (SCB
not offer a feasible method of controlling contaminant exposures at wi
fires. Airline respirators are not practical because of the remote lo
topography of the environment, and distances traveled during wildland
suppression. SCBAs have too short of a service life (generally 30 min
less), and are too heavy and bulky for the fire fighters to carry whil
performing fire suppression.

Administrative controls aimed at reducing the time that fire fighters
exposed to elevated SO_2 concentrations could effectively reduce SO_2 exp
Options include shortening the duration of the workshift and/or restri
the fire fighter from areas where SO_2 concentrations are above the REL
suppression agencies may choose to rely on administrative control meth
depend on smoke intensity; however, that requires an objective assessm
intensity. Currently, smoke intensity is a subjective judgement made
suppression personnel based primarily on visual observation. (It is w
noting that overexposures to SO_2 occurred at the Gauley Mountain Fire
though the smoke intensity was judged to be low to moderate by fire fi
Furthermore, there is no evidence that smoke intensity, even if based
objective data, reflects the air concentrations of individual contamin
Routine monitoring of workers under various wildland fire conditions i
only reliable method of determining fire fighters' exposures to indivi
compounds.

Formaldehyde exposures ranged up to 0.10 ppm. The average exposure wa
0.07 ppm. NIOSH considers formaldehyde to be a potential occupational
carcinogen, and recommends that exposures be reduced to the lowest fea
level. Exposures to furfural ranged up to 0.03 ppm. This concentrati
well below the OSHA PEL of 2 ppm. Exposures to acetaldehyde and acrol
below the minimum quantifiable concentration (MQC). The MQCs for acet
and acrolein are 0.06 and 0.02 ppm, respectively. These MQC values ar
on a sample volume of 28 liters. VOCs were not detected. The minimum
detectable concentration (MDC) for a 29 liter sample is 0.03 mg/m^3 for
benzene; and 0.3 mg/m^3 for toluene, xylene, and trimethylbenzene.
RPM exposures ranged up to 1.5 mg/m^3. The average exposure to RPM was
0.49 mg/m^3. Crystalline silica was not detected. The MDC for a 890 l
sample is 0.02 mg/m^3 of silica. Air concentrations of benzene soluble
up to 0.67 mg/m^3; however, PAHs were not detected on these samples. T
for a 530 liter sample is 0.9 µg/m^3. Concentrations of naphthalene fr
PAH tube samples ranged up to 6.1 µg/m^3. This is well below the NIOSH
50 mg/m^3. Exposures of other PAHs detected on the tube samples;

acenaphthylene, acenaphthene, and fluorene, were below the MQC. The M
530 liter sample is 3 µg/m³.

The air concentrations of contaminants measured at the visitors center
low. The air concentration of CO was one ppm and SO_2 was not detected
limit of detection (LOD) of the method used to measure SO_2 is reported
0.7 ppm for an 8-hour sample.[5] The formaldehyde concentration was bel
MQC of 0.03 ppm for a sample volume of 30 liters. Neither acetaldehyd
acrolein, nor furfural were detected. The MDCs for a 28 liter sample
0.02, 0.006, and 0.003 ppm for acetaldehyde, acrolein, and furfural,
respectively. VOCs were also not detected. The air concentration of
0.07 mg/m³. Crystalline silica was not detected. The benzene-soluble
concentration was 0.11 mg/m³; however, PAHs were not detected on this
PAHs were not detected on the tube portion of the sample either. The
a 530 liter sample is 0.9 µg/m³. These measurements indicate that con
concentrations at the visitors center were low and did not pose a heal
concern for visitors, or park personnel working at the center.

The dirt roads from which backfiring occurred, served as natural fire
This precluded the need for direct attack fireline construction. Expo
during direct attack, what some fire suppression personnel believe may
the worse case exposure conditions, were therefore not measured. Disc
with crew members from several Type 1 crews has suggested that prolong
direct attack does not frequently occur. It may be unrealistic to exp
investigations performed at a few fires to provide data on what may be
relatively rare event. Routine exposure monitoring of crews would imp
probability of collecting exposure data during direct attack line
construction. The monitoring of individual fire fighters for an entir
season would provide both daily (short-term) and seasonal (long-term)
exposures. This might best be accomplished by assigning an industrial
hygienist to a fire crew for the duration of a fire season.

Many factors affect a wildland fire, but probably none more so than th
weather. Despite improved weather forecasting, local weather events a
unpredictable. This unpredictability, as it relates to fire behavior,
intensified because the fire itself influences wind patterns. Unpredi
changes in weather, and the subsequent changes in fire behavior, are f
that influence the effectiveness of suppression activities at extingui
the fire. Similarly, the effectiveness of data collection efforts are
influences by unpredictable weather and fire behavior. NIOSH teams ha
arrived at several fires since 1988, only to be notified that the fire
nearly controlled.

An alternative to collecting exposure data at wildfires is to collect
prescribed burns ignited by fire suppression personnel. These are pla
events that coincide with predicted weather patterns. Because the wea
fire behavior is likely to be more predictable, exposure studies of pr
burns such as the study performed by the United States Forest Service,
prove to be more productive. One argument against using data from pre
burns, is that the data would not represent exposures at wildfires. C

evidence that supports this argument however, does not exist. It is u
though, that monitoring at a prescribed burn would provide exposure da
direct attack, unless the fire escaped its prescription.

RECOMMENDATIONS

1. Administrative controls to reduce the fire fighter's exposure to
    should be determined by the NPS and other agencies responsible fo
    suppression. If controls are used which depend on smoke intensit
    objective criteria for assessing the intensity should be establis

2. Routine exposure monitoring of the crews during fire suppression
    activities should be conducted. This can best be done by the NPS
    other agencies responsible for fire suppression. Although settin
    such a program is a large task and would require additional resou
    it is an important measure for assuring the health and safety of
    fire fighters.

3. The monitoring of individual fire fighters for the entire fire se
    should be conducted to provide both daily and seasonal exposures.

4. The focus of future research efforts should include data collecti
    prescribed burns.

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be posted by the employer in a prominent place accessible to the emplo
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Appendix I

Using the CFK equation to adjust the NIOSH REL for CO

In the NIOSH document: "Criteria for a Recommended Standard...Occupat
Exposure to Carbon Monoxide,"[7] NIOSH used the Coburn, Foster, Kane (CF
equation to develop the NIOSH REL for CO of 35 ppm, as an 8-hour TWA.
the exposure level that would result in a 5% COHb level in workers exp
sea level, involved with a sedentary level of work activity, and expos
8 hours per day. The CFK equation is:

$$[CO] \text{ ppm that results in 5\% COHb} = \frac{1316\{AC - V_{CO}B + a(V_{CO}B - AD)\}}{1 - a}$$

where:

$$A = P_{C-O2} \div M(O_2Hb)$$

$$B = (1 \div D_L) + (P_L \div V_A)$$

$$a = e^{-AT/V_bB}$$

The variables in the above equations were given in the NIOSH criteria
for CO and are presented below:[7]

C   =   COHb concentration at time T; 0.01 ml COHb/ml blood (5%
            COHb).

D   =   background COHb level at time=0; 0.0015 ml COHb/ml bloo
            (0.75%).

V_{CO} =   rate of endogenous CO production; 0.007 ml/min.

V_b =   blood volume; 5500 ml.

O_2Hb =   oxyhemoglobin concentration; 0.2 ml/ml blood.

M   =   ratio of affinity of CO vs. O_2 to hemoglobin; 218.

T   =   length of workshift in minutes; 480 minutes.

D_L =   CO diffusion rate through lungs for sedentary level of
            activity; 30 ml/min/mm Hg.

V_A =   lung ventilation rate for sedentary level of activity;
            6000 ml/min.

P_L =   dry barometric pressure in the lungs in mm Hg. In the I
            criteria document, NIOSH used the standard atmospheric
            pressure at sea level minus the pressure of water vapor
            body temperature (760 mm Hg - 47 mm Hg = 713 mm Hg).

P_{C-02} = partial pressure of oxygen in the capillaries; 100 mm Hg

Many of these variables are constants based on physiological processes
of the variables can be changed from those used in the NIOSH criteria
to better describe the work environment of the forest fire fighter. C
in these variables by the NIOSH investigators can be classified into t
categories: length of workshift, level of work activity, and altitude

Length of Workshift (T)

NIOSH used an 8-hour workshift (480 minutes) in calculating the RE
35 ppm. Although forest fire fighters typically work 12-hour shif
day, the NIOSH investigators retained the use of 8 hours in their
calculations because this reflects the time period that was monito

Level of Work Activity (D_L and V_A)

The NIOSH criteria document lists the variables D_L and V_A which we:
in the CFK equation to define level of work activity.[7] The values
these variables represent three levels of work activity: sedentar
light, and heavy. These variables and values are shown below.

Work Activity Level	D_L	V_A
Sedentary	30 ml/min/mm Hg	6000 ml/min
Light	40 ml/min/mm Hg	18000 ml/min
Heavy	60 ml/min/mm Hg	30000 ml/min

In calculating the NIOSH REL of 35 ppm, NIOSH used the D_L and V_A va
for a sedentary level of work activity.[7] The NIOSH investigators
Thompson Creek forest fire contend that using the values for heavy
activity would be more descriptive of the work. Thus, the above v
for a heavy work activity level were used by the NIOSH investigato
their calculations.

Altitude (P_L and P_{C-02})

The two variables within the CFK equation that are directly affect
altitude are the dry barometric pressure in the lungs (P_L) and the
partial pressure of oxygen in the capillaries (P_{C-02}). The adjustm
these variables to reflect the effect of altitude, as related to t
equation, was previously discussed in an U.S. Department of Health
Human Services, Public Health Service intra-agency memorandum.[22] '
following will present the changes in these variables caused by e:
to CO at an altitude of 7000 ft. P_L is the most obvious variable
CFK equation that would be effected by altitude. In the NIOSH cr:
document, NIOSH used the standard atmospheric pressure at sea leve
minus the pressure of water vapor at body temperature (760 mm Hg
47 mm Hg = 713 mm Hg).[7] To calculate P_L, the NIOSH investigator u:

737 mm Hg. This is the average value of three measurements of
barometric pressure made on 11/4/91 using a Thommen altimeter-baro
This pressure corresponds to the elevation of approximately 1000 f

In discussing altitude, Best & Taylor[24] state that the partial pres
of water remains the same, and is only dependent on body temperatu
Thus, 47 mm Hg was subtracted from these values to obtain the P_L.

The partial pressure of oxygen in the capillaries (P_{C-02}) is direct
related to the atmospheric pressure. From the above intra-agency
memorandum[22], P_{C-02} can be calculated using the following formula

$$P_{C-02} = P_L \times 0.21 - 45$$

Using the above given values for C, D, V_{CO}, V_b, O_2Hb, T and M; the
calculated values for A, B, and a; and the new values for V_A, D_L,
P_{C-02}, the NIOSH investigators calculated the maximum CO exposure
concentration which would result in a 5% COHb level in most worker
For forest fire fighters working at a heavy activity level at an
altitude of 1000 feet for eight hours, the CFK equation predicts t
5% COHb level will be reached at a CO exposure concentration of 30
Although the typical work shift of the fire fighter is 12 hours,
observed that on the days during monitoring, the majority of this
four hours was spent in travel to and from the worksite. The
contributed exposure to the fire fighters during travel for this
particular fire was estimated to be low.